Nanostructured Diffraction Grating Elements fabricated by Deep UV reduction photolithography."

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LightSmyth Technologies

Crafting Light For The Information Age
LightSmyth Technologies

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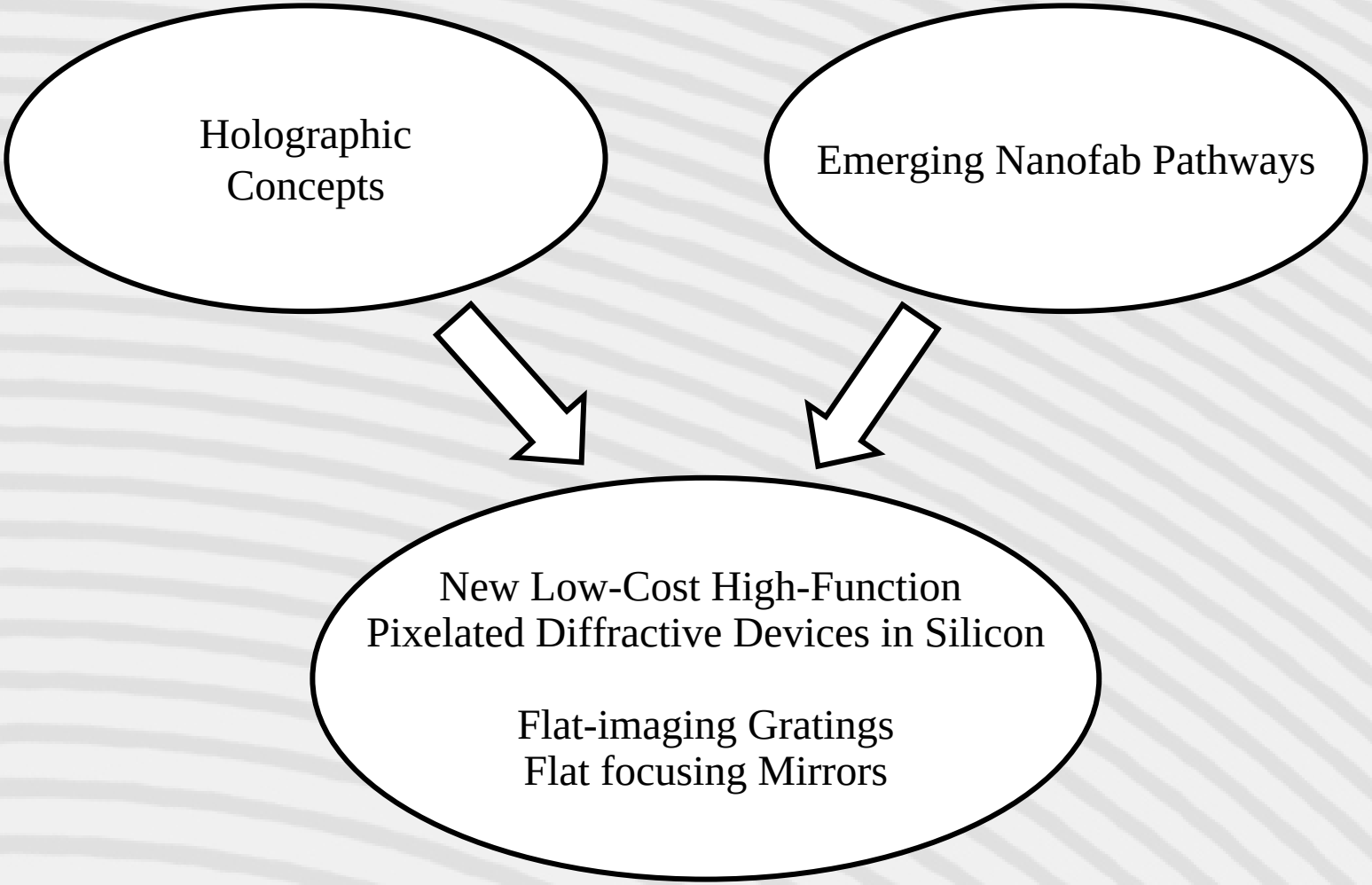
Programmatic Facts

- Current results supported by NASA Phase I SBIR (NNG-06-LA-10C). NASA monitor: Dave Content
  - Related to gratings for Constellation X, Nexus
- Related work funded by DARPA Phase II SBIR (W31P4Q-05-CR149) DARPA monitor: Jag Shah (integrated holographic devices).

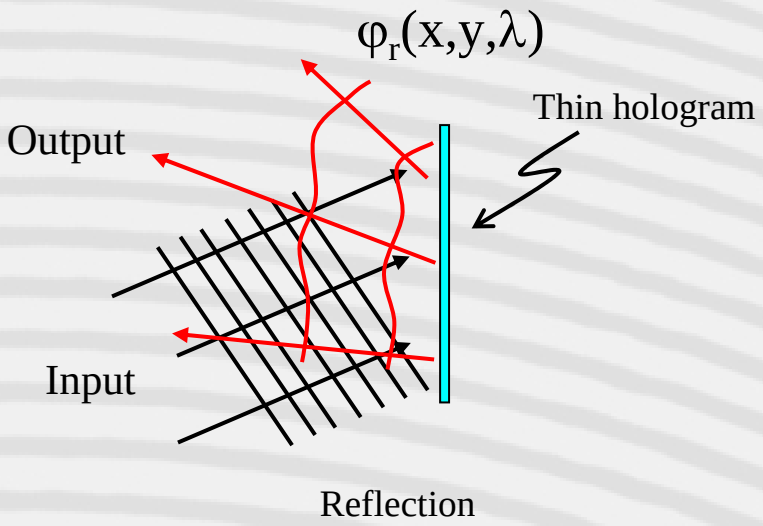
Gratings and Diffractives: Fab Methods

- Ruling
  - Relatively low line count, blazed, possible variable line spacing (1D focus)
- Interference-based fab (loosely called holographic)
  - Higher line count, blaze hard, line pattern limited by writing beams
- Present method: DUV photolithography from reticle
  - Up to 10,000 L/mm (getting higher every year)
  - Completely arbitrary line curvature and spacing (2D focus/wavefront control)
  - Blaze possible but less needed due to high line count

New fabrication approaches support functional innovation



Holographic Principle
(Arbitrary wavefront transformation from flat optic)



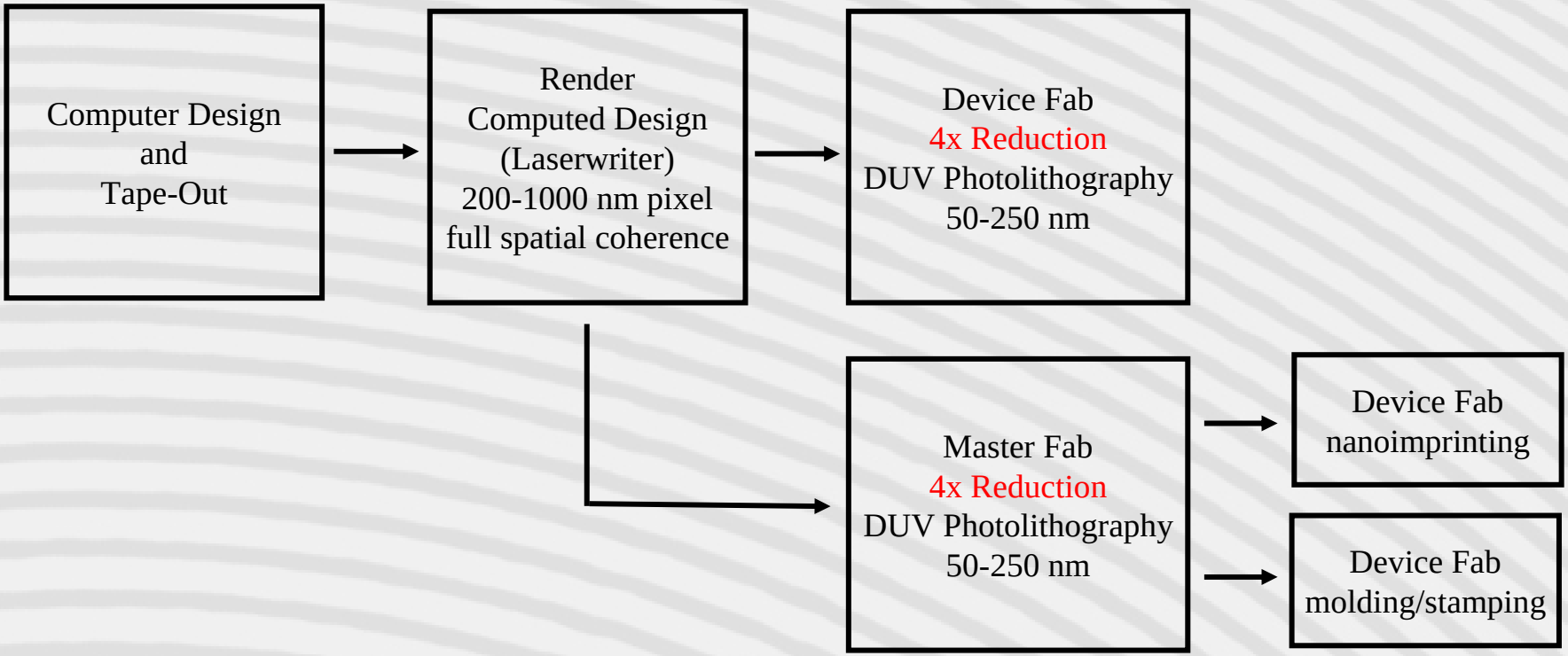
- Single flat element provides focusing/imaging PLUS dispersion
- Requirements
  - arbitrary diffractive pattern
  - resolution better than ≈λ/4 (≈100 nm visible)
  - spatial coherence over aperture
- Fabrication Approaches
  - Past – interferometric exposure
  - Future Opportunity
    - compute
    - laser write
    - reduce via photolithography

Pixelated Flat Diffractive Imaging Mirrors/Gratings 26x33-mm single field, 10^{11}-10^{12} design pixels

- Flat Imaging Gratings
  - Variable Line Spacing
    - dispersion (horz) plane focus
  - Curved Contours
    - Vertical plane focus
  - Multiple Coherent Facets
    - Wide spectral coverage
    - High resolution
    - Efficient use of 2D detector
- Easy to replicate
- Up to 10,000 lines/mm

- Flat Diffractive Mirrors
  - Arbitrary wavefront transformation
    - image
    - focus
    - collimate
    - spherical-cylindrical
    - off-axis
  - Replication friendly (no curved surface)
  - Optimal narrow-band signal

Photolithographic Nanofab pathway



Final Devices:
cm-scale pattern, Full spatial coherence, 50-250 nm feature size, Low-cost mass production via stepper/nanoimprint/injection molding

Laser Mask Writer – Arbitrary Pattern, Submicron Pixels

Micronic Laser Systems AB

- Write time (6” mask) 1 h 45 min
- Minimum main feature 220 nm
- Address grid 1.25 nm
- CD uniformity (global, 3 σ) 7 nm
- Registration (global, 3 σ) 15 nm

Modern DUV Reducing Stepper/Scanner

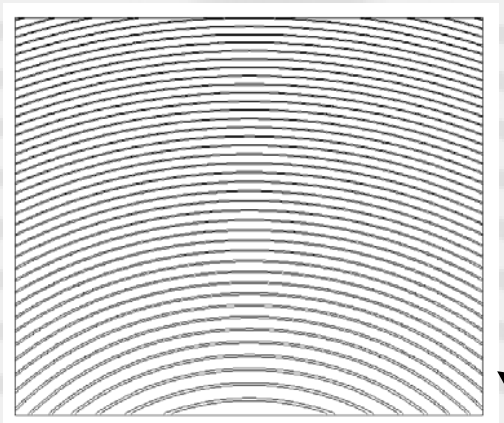
- Reduction Factor 4x (from mask)
- Resolution 65 nm
- Field Size 26 X 33 mm
- Throughput 122 wph

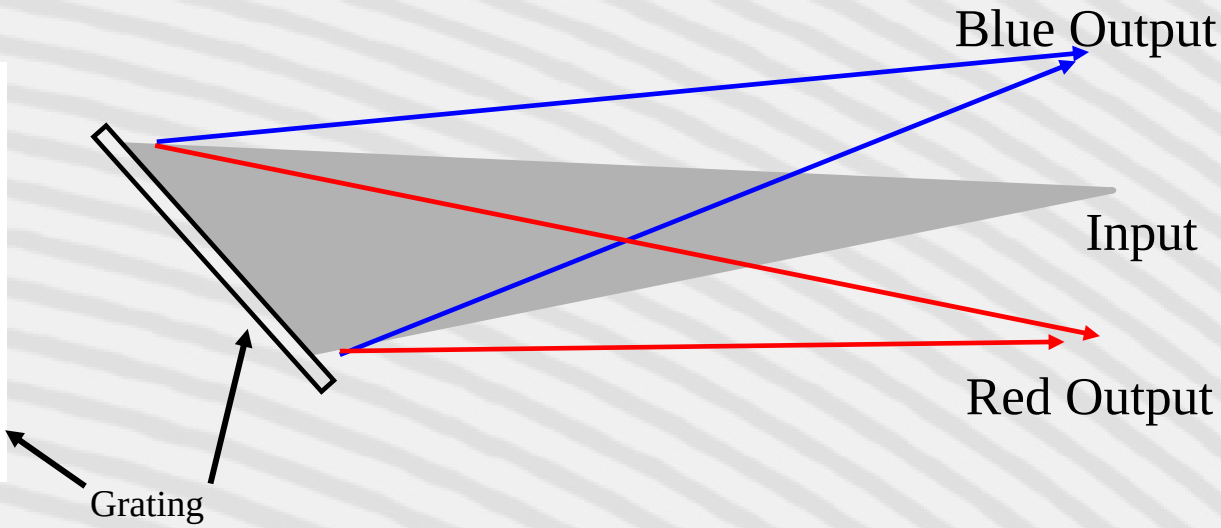
  300 mm wafers

  125 exposures

Focusing Diffractive Gratings

Focusing Grating Surface Profile
(schematic)





Lithographically-Ruled, Flat, Complex Contour Grating (10^{11} pixels)

Multiple functions/single optical device
- focusing + spectral dispersion

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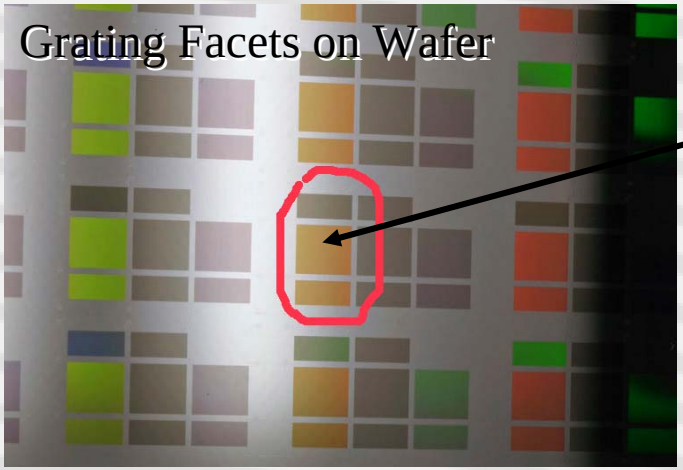
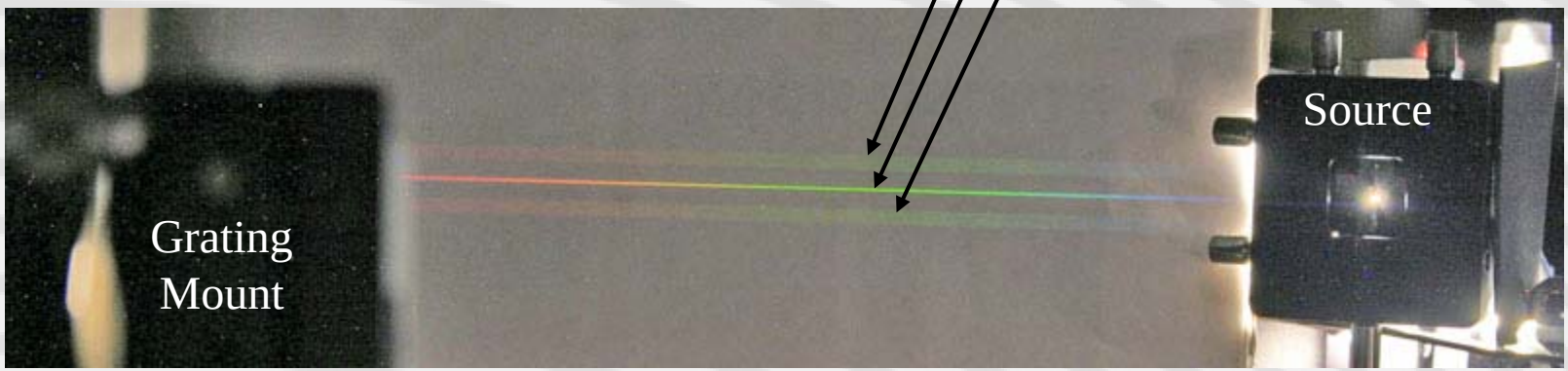
Demonstrate Flat-Focusing Grating Concept (NASA Phase I SBIR)

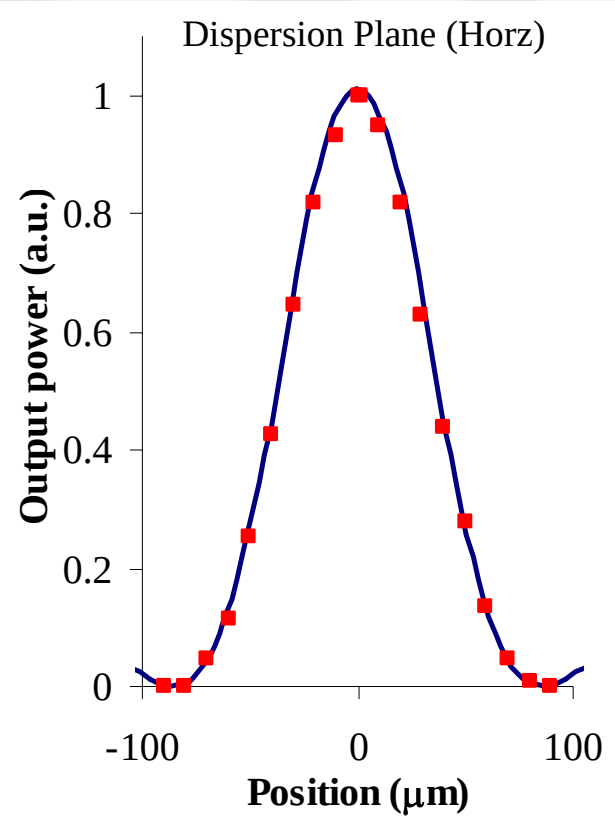


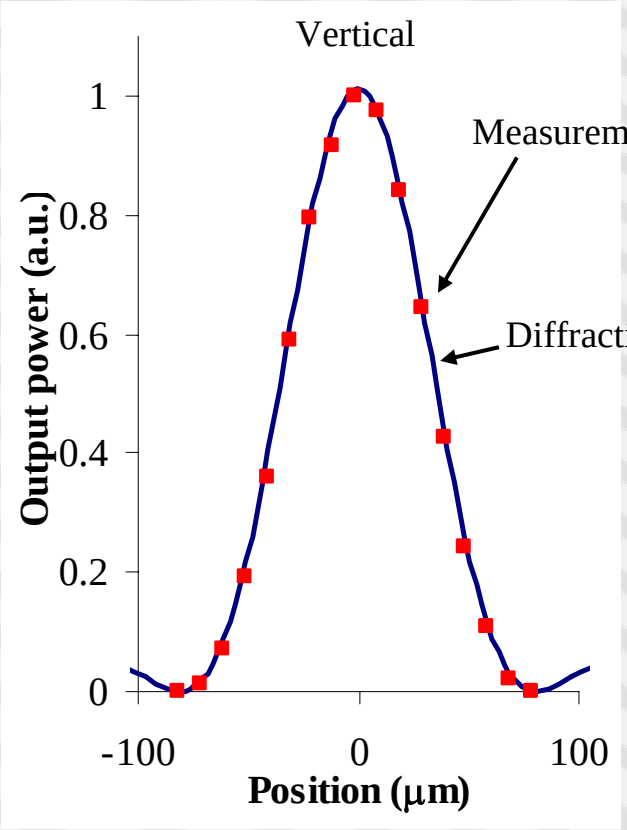
4x5 mm
2100 L/mm

1D focusing
2D focusing
1D focusing

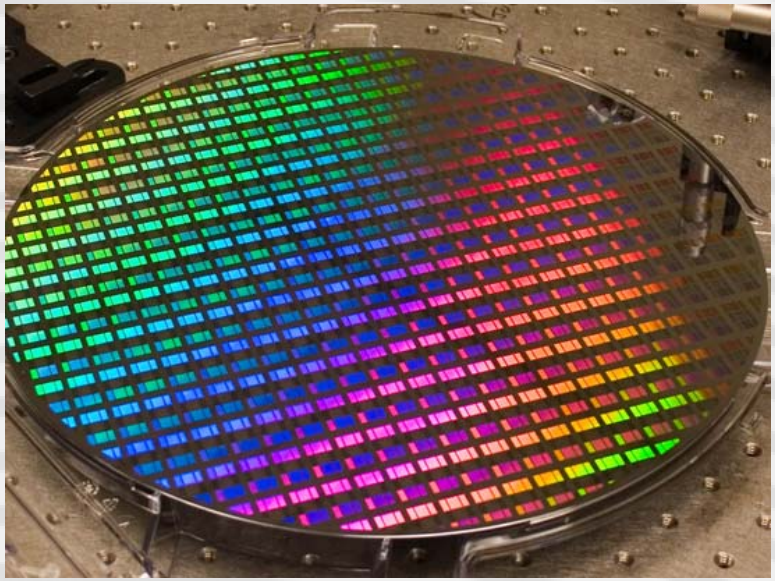


Diffraction-limited Focusing Demonstrated





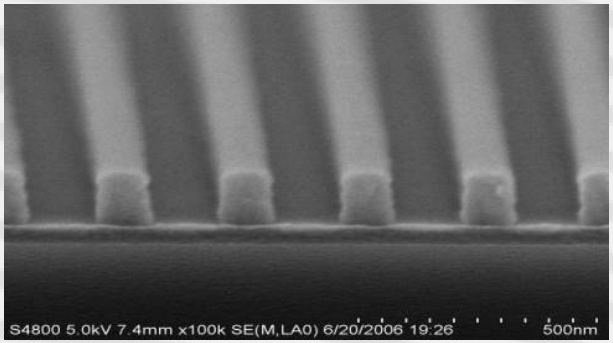
Lithographic Flat Focusing Gratings



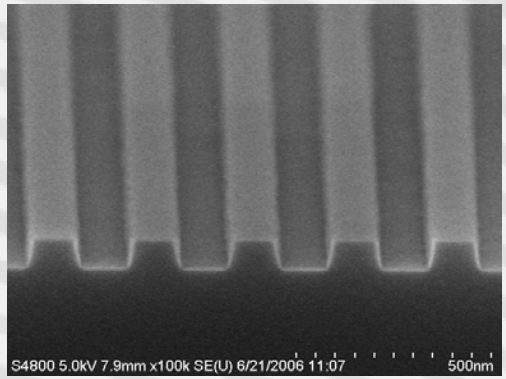
- First new approach to grating fab since holographic exposure (40 years)
- Arbitrary line curvature, spacing combines imaging and dispersion on flat substrate (up to 10,000 lines/mm (50-nm resolution))
- Full spatial coherence (26x33 mm field)

Patterning and Etch

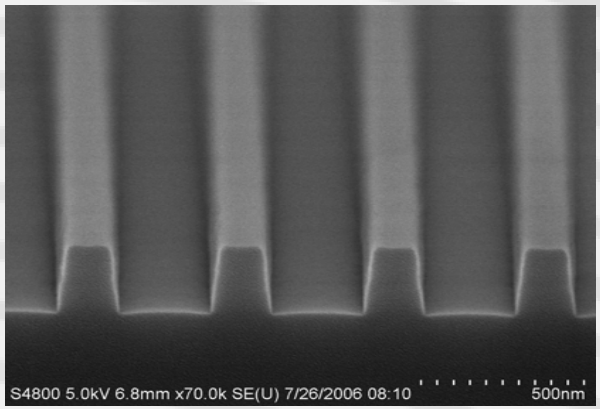
Patterned Photoresist

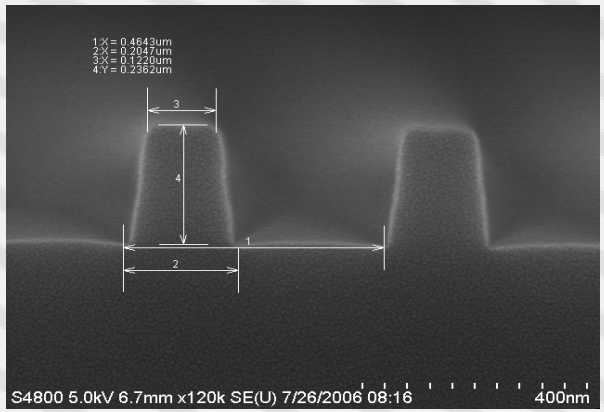


Etched Silicon



Etched Si
Deeper Etch

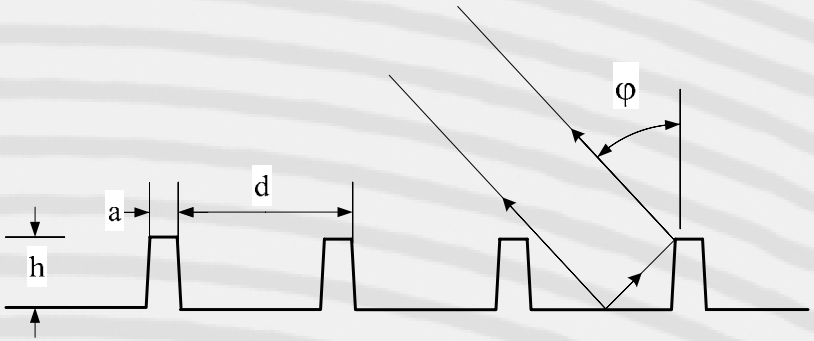




500 nm
pitch

Blazing

- Important when grating supports multiple orders
  - Marginal importance when line spacing ≈ signal wavelength
- Blazing methods available
  - Anisotropic etch for slanted facet
  - “Corner Prism” blaze for Littrow
  - Sub-wavelength binary etch provides effective phase ramp



Optimum etch depth:
$h = \frac{1}{2}(d-a)/\tan\varphi$

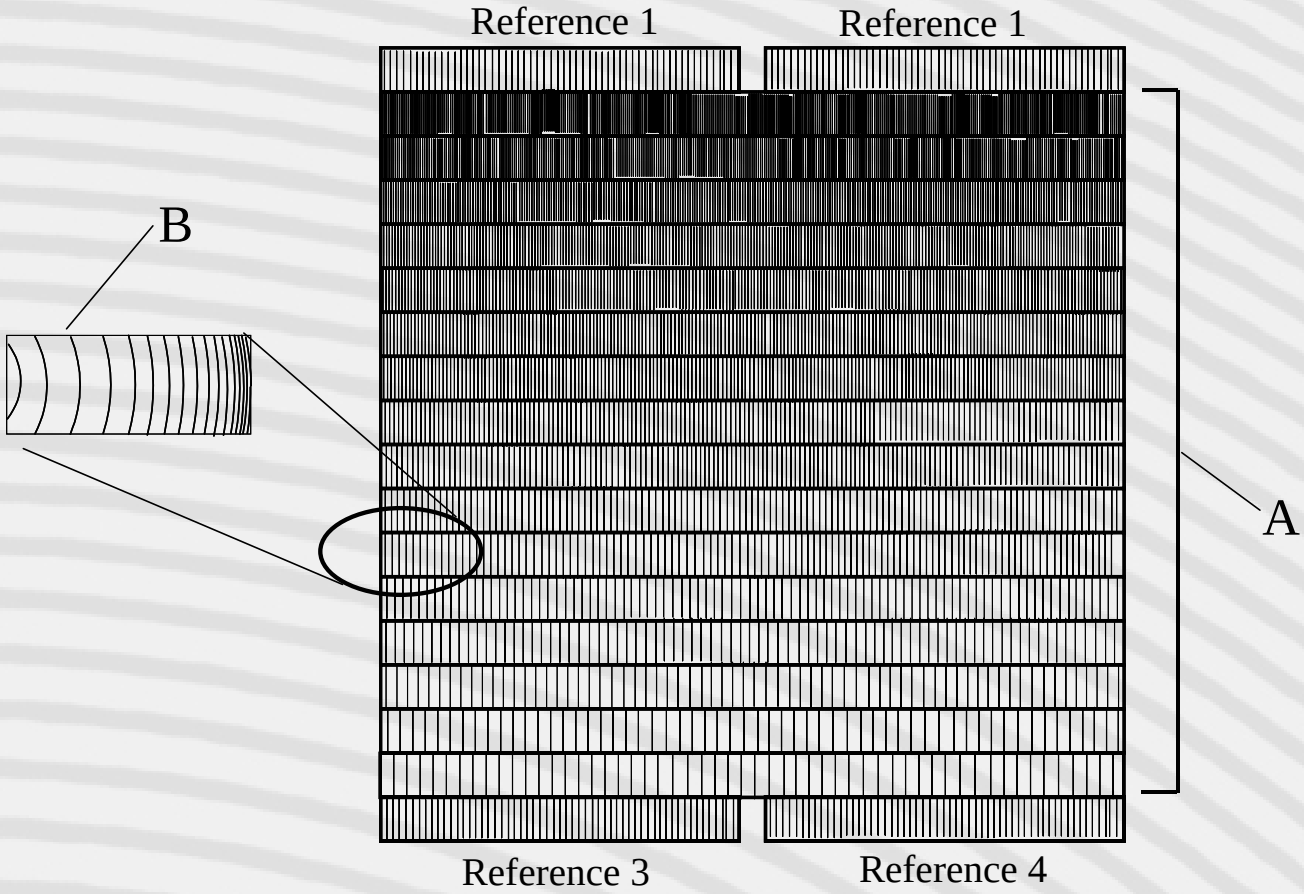
Efficiency: $(d-a)/d$

Corner Prism Blaze for Littrow

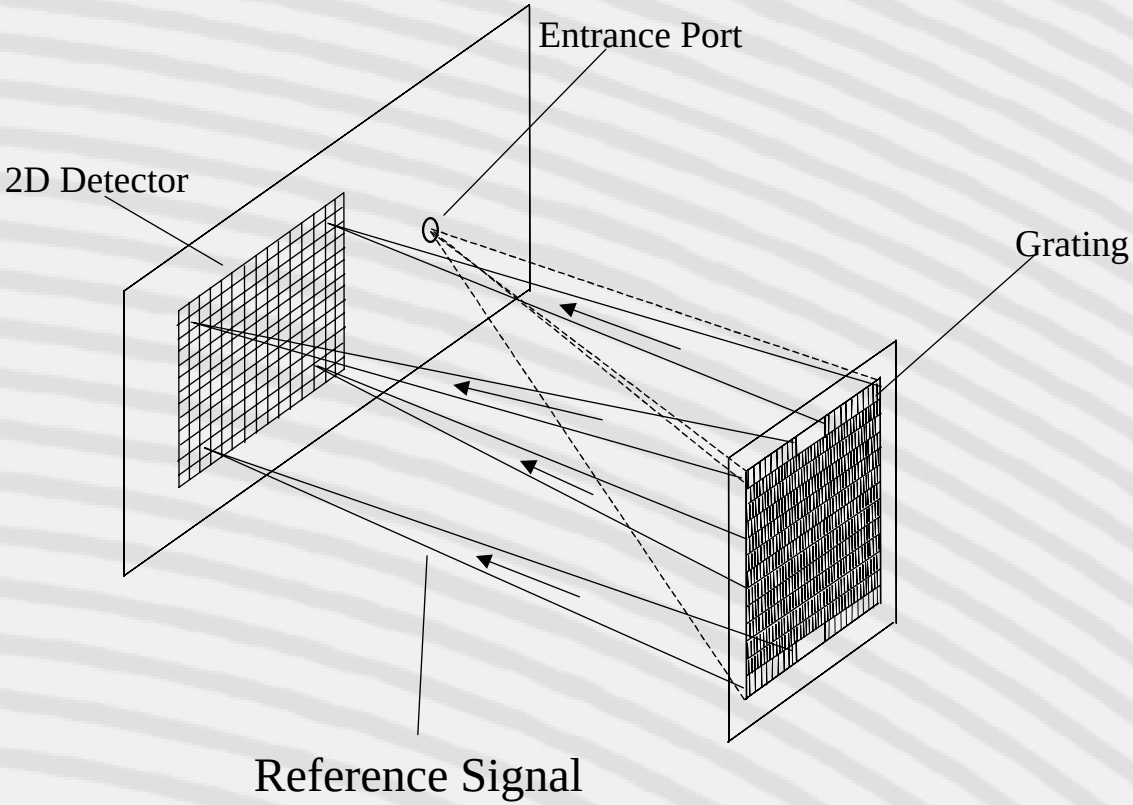
NASA Related Applications

- X-ray/EUV/UV gratings (Constellation-X, Nexus)
  - High Line Count
  - Variable line spacing
  - Off-axis
  - 2D focusing
- High Resolution + Broad Bandwidth (ChemCam – MSL)
  - Multi-facet
  - High Efficiency

Multi-faceted Grating for LIBS Spectroscopy (ChemCam – MSL)



Multi-faceted Flat Focusing Grating with 2D detector and Universal Calibration



Summary

- Semi-conductor patterning tools open new era in grating design
  - flat substrate (Silicon or replicate to other substrate)
  - focusing
  - dispersion
  - coherent multi-faceted gratings
- Useful in multiple NASA programs
  - Constellation-X
  - Nexus
  - ChemCam-MSL (and future variations)
- Pathway to low-cost volume production via direct photolithographic patterning or via replication of master